

Defining and Applying Limits for Test and Flight Through the Project Lifecycle GSFC Standard

1

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TFAWS
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SCOPE: NON-CRYOGENIC SYSTEMS TESTED IN VACUUM

This course describes the standard method that the GSFC thermal branch utilizes. Other NASA centers or private companies may implement temperature limits in different manners.

What You Will Learn

2

- **Project Lifecycle: Evolution of Limits and Branch Products**
- **Developing the Requirements Table: Flight Limits**
 - Flight Limits Definition
 - How Limits Should be Generated
 - Gradients/Limits Location
 - Working with the Component PDL
 - Gold Rules Margins
- **Developing the Requirements Table: Test Qualification Goals**
 - Test Margin Definition
 - Qual versus Acceptance
 - Passive Versus Active
 - GEVS requirements
 - Role of Analysis Predictions
 - Limits Tolerances

Acronyms and Reference Documents

- AFT- Allowable Flight Temperature
- CM – Configuration Management
- CPL -Capillary Pumped Loop
- Ebox- Electronics Box
- GEVS – General Environmental Verification Specification
- GOLD - Goddard Open Learning Design
- GSFC – Goddard Space Flight Center
- LHP-Loop Heat Pipe
- MEB – Main Electronics Box
- NEI – Non-explosive Initiator
- Op – Operational
- PDL – Product Design Lead
- PDR- Preliminary Design Review
- PG – Procedures and Guidelines
- S/C – Spacecraft
- SRR- Systems Requirements Review
- STD- Standard
- TEC-Thermo-Electric Cooler
- TVDS – Thermal Vacuum Data System

Documents that govern GSFC Limits:

- 545-PG-8700.2.1.B (Branch Guidelines)
- GSFC-STD-7000 (GEVS – Standards for Testing)
- GSFC-STD-1000 (GOLD rules – Standards for Design/Testing)

What You Will Learn

4

- **Developing the Test Sensor Limit Spreadsheet**
 - Yellow Versus Red Test Limits
 - Sensor Position
 - GEVS Wording
 - Progression of Qualification Goals throughout the Test Program
 - Reality of Testing (Helpful Hints)
- **Developing the Flight Sensor Limit Spreadsheet**
 - Yellow Versus Red Flight Limits
 - Guidelines – Mode Based Limits
 - Reality of Flight Database (Helpful Hints)
- **Summary of Branch Policies on Limits**

Examples interspersed throughout this package:

- Example1 - Defining the Limits for Requirements Table
- Example 2: Defining the Qualification Goals for the Requirements Table
- Example 3: Qualification Goal from Analysis Predictions
- Example 4: Determining the Test Sensor Limit in the Database at the Requirement Location
- Example 5 : Test Limits and Sensor Position
- Example6: Progression of Qualification Goals and Associated Tolerances
- Example 7: Implementing Flight Limits

Project Lifecycle: Evolution of Limits

5

SRR Limits Requirements

Developed and Owned by Component PDL

Limits based on Hardware/science constraints

Spreadsheet of Limits maintained by Systems Engineer & changes agreed upon

Test Qual Goals Requirements

GSFC Policy is a MINIMUM goal of 10 C Op margin over AFT

No margin on Survival Limits (with PDL agreed to temperature tolerances)

PDR Limits Requirements

SRR limits may have been adjusted based on updated information on design

Thermal Branch Recommends that project have thermal limits under configuration management at PDR

Test Limits

- The requirements table is used to determine sensor limits based on analysis.
- Developed for both flight and test sensors
- Modified as needed from component level to higher assembly tests
- Includes the test tolerances agreed upon by component PDL

Flight Limits Database

- Based test qualification extremes and correlated flight model predicts
- Developed per "State " (i.e. operational, safhold, survival, decontamination, etc)
- Yellow limits may be modified based on flight data

Project Lifecycle: Evolution of Branch Products

6

SRR Limits Requirements

Product

Table of Limits
(Op, Non-Op, turn On)

Control

Project Systems
Engineer

Test Qual Goals Requirements

Product

Table of Limits
(Op, Non-Op, turn On,
Qual Goals)

Control

Project Systems
Engineer

Additional Agreement
with PDL and project
on limits tolerances

PDR Limits Requirements

Product

Table of Limits
(Op, Non-Op, turn On,
Qual Goals)

Control

Project CM

Test Limits Database

Products

Spreadsheet
(Red/Yellow Test Limits)
Table
(Qual goals/Tolerances)

Control

Thermal PDL
(Included in Test Plan
with project CM)

Flight Limits Database

Product

Spreadsheet
(Red/Yellow Limits
per mode)

Control

Developed by
Thermal PDL and
CM of Project
Flight Database

TYPES OF LIMITS PRODUCTS

TABLE OF LIMITS

*Thermal Requirements
Shown in Reviews
Op/Non-op
Flight/Qual*

SPREADSHEET OF TEST LIMITS

*Sensor-by-Sensor
Op/Non-Op Test
Conditions*

SPREADSHEET DATABASE OF FLIGHT LIMITS

*Sensor-by-Sensor
Mission Modes Flight*

DEVELOPING THE REQUIREMENTS TABLE

“Flight Limits”

7

THE PRIMARY DEVELOPMENT OF THE REQUIREMENTS TABLE IS FROM SYSTEMS REQUIREMENTS REVIEW (SRR) THROUGH PRELIMINARY DESIGN REVIEW (PDR). SOME UPDATES MAY BE MADE AFTER PDR BASED ON DESIGN MATURITY.

Limits Definition

8

- **Op Limits** (Allowable Flight Temperature AFT): The project approved minimum/maximum mission allowable temperatures when the component is operating.
- **Non-Op Limits** (Survival): The project approved minimum/ maximum mission allowable temperatures when the component is not operating.
GSFC Terminology: Non-Op = Survival
- **Turn-On Limits**: The temperature that the component may be powered on and operated without damage; however the performance may not be within spec.



Turn-On Limits MUST be at least as wide as the Op qualification range but may be wider

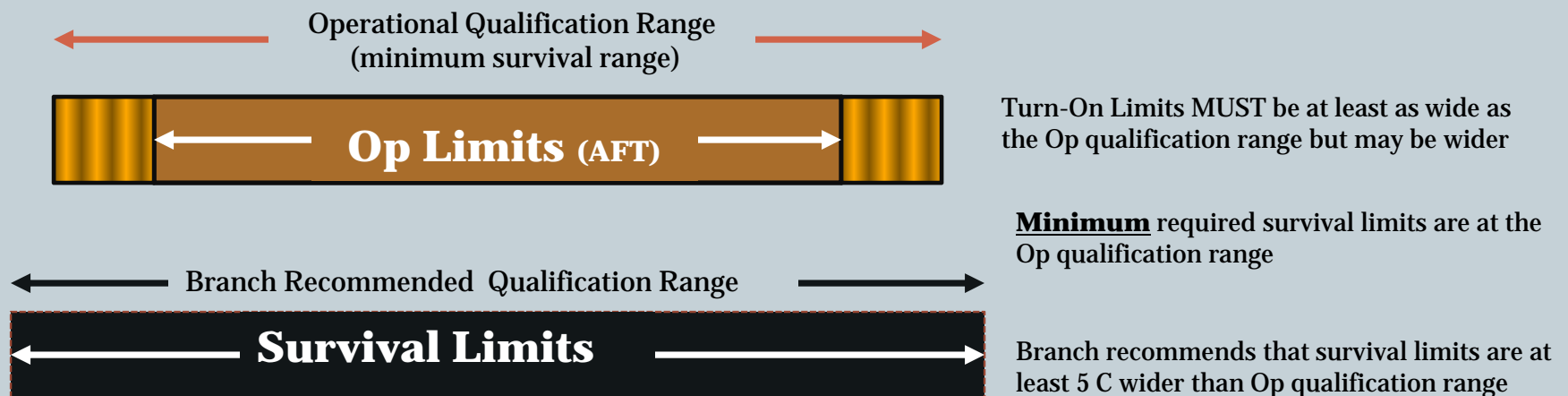


Minimum required survival limits are at the Op qualification range

Qualification Range Based on Limits

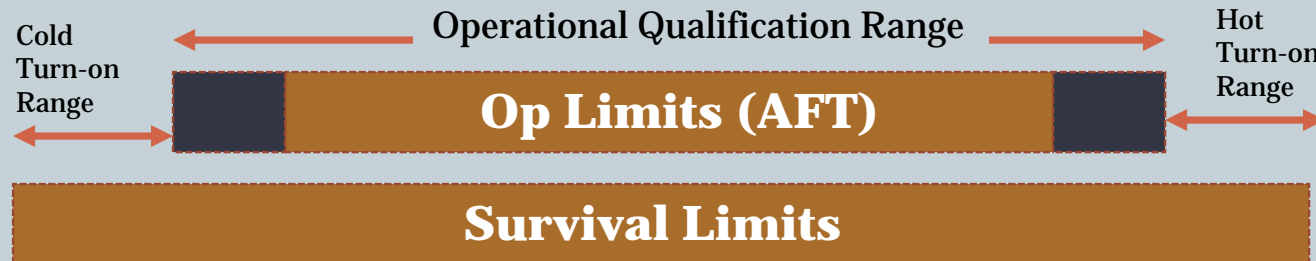
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- **Op Qualification Range:** Typically $\pm 10^{\circ}\text{C}$ more extreme than AFT limits. The component must operate ***within spec*** at qualification temperature levels.
- **Non-Op (Survival) Qualification Range:** There is no margin required for survival qualification (the survival limit and the survival qualification range are the same). The minimum required survival limits are at the Op Qualification Range; However the branch recommends that survival limits are at least 5°C wider than this.



Turn On Limits

10



Cold Turn On Limit

- *The cold turn-on limit shall be set at or between the cold survival limit and the cold operational qualification range.*
- *For cold turn-on limits below the operational limit there shall be a method of warming the component (i.e. active method such as heaters or self warming).*

Hot Turn On Limit

- *The hot turn-on limit shall be set at or between the hot operational qualification range and the hot survival limit.*
- *For hot turn-on limits above the operational qualification range the thermal engineer shall verify that no limits (internal or external) would be exceeded when power is applied.*

How Should Original (SRR) Limits Be Determined?

11

- Mechanical Limitations
- Electrical Part Limitations
- Vendor Data: Previous Qualification (with Proper Derating)
- Coating or Heater Constraints: Survival/Adhesion
- Working Fluid Limitations: Heat pipes
- Science Constraints: Op Range (Instruments)

The Hardware PDL owns the limits!

Original Limits should NEVER be based on thermal predicts.

Location of Limits and Gradients

12

- The location of where the limits requirements apply needs to be defined and understood.
 - Based on how the item is controlled and tested
 - At interfaces or directly on component
 - Location of sensors

Although Limits can be defined ANYWHERE if the component PDL does not have a specific location where the limit needs to be defined the branch guidelines are as follows:

Conductive Mounted Ebox (primary heat transfer through base) Recommended Location: at mounting interface on substrate

Isolation Mounted Ebox (primary heat transfer through radiator) Recommended Location: near radiator or at control sensor/thermostat location if actively controlled (e.g. heater on ebox)

Other Actively Controlled Critical Components:
At Control sensor/thermostat location

Instruments – Recommended Location: at mounting interface on spacecraft surface. If isolated both ends of isolator should have temperature requirements.

Working With the Component PDL

SSR to PDR Level

13

Determining Limits:

- The limits should be based on the hardware constraints. However, at this early phase in the project, it may be difficult for the PDL to determine his exact limits. Component PDL should be able to establish limits with rationale based on heritage if a similar design has flown.
- In many instances the project will attempt to base the limits on the thermal predictions. However the thermal design/analysis is impossible without knowing the hardware constraints. Consult branch management for preliminary temperature ranges if PDL is unable to set limits.
- Limits (and their location) are iterated through PDR as the design matures. The systems engineer should keep a listing of the limits and rationale for changes.
- Qualification Goals, Limits, and Test Tolerances are developed AFTER the Op and Non-Op limits are defined.

Questions to Ask PDL/Systems:

- What is the temperature range that the component can operate within spec? (The AFT requirements are derived by subtracting the qualification margin)
- What is the temperature range that the component can operate but may not be in spec? (Cold/Hot turn-on Limits)
- What is the temperature range that the component can survive if powered off? (Survival limits)
- Is there a specific location where the limit should be defined? If not then follow branch guidelines for limit location.
- When do these limits apply? (For example the “Op” limits for dampers, actuators, etc. may only apply during deployment).

Example 1 : Defining the Limits for Requirements Table

14

The PDL on the main electronics box (MEB) on the WTE (wonderful thermal experiment) is allowing the box to be operational at -30 to +40° C and non-operational at -30 to + 55° C. Define the AFT, survival, and turn-on limits.

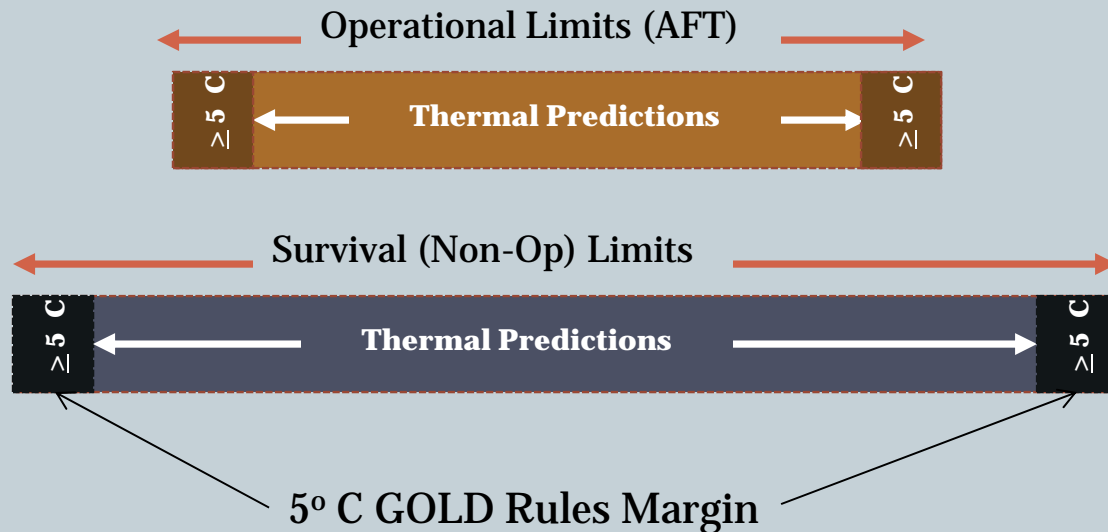
Limit Type	Limits	Notes
Operational (AFT)	-20 to +30° C	At SSR the PDL may not know whether the component will be actively or passively controlled. You'll learn about the differences in the next section. Until this is determined assume that the AFT is $\pm 10^{\circ}$ C the maximum allowable operational range. Limits will be iterated as the design matures.
Survival	-30 to +55° C	This is the range that the component PDL provided. This meets the minimum requirement of 10° C more extreme than the AFT temperatures; However the branch recommends $\pm 15^{\circ}$ C. Ask the PDL if the hardware survival limit could be -35° C..... The original number that he/she gave you might have been based on the minimum GEVS requirement and not a physical restriction of the hardware.
Turn-On	-30 to +40° C TBR	The component PDL did not provide enough information to determine the turn-on ranges. The minimum range is shown; however the component may be able to be ON until it reaches +55° C.

Note that the thermal PDL will also need to work with the component PDL to define the location that the requirement applies. Thermal PDL should explain that there are gradients within the component and test tolerances that allow temperatures to be outside the requirements table range.

Analysis and Gold Rules Margin

15

- Just a note that once the limits have been defined the thermal predictions should verify that there is at least 5° C margin. **Before** going to a more complex thermal control system inform the component PDL and systems engineer of the resources that would be needed (radiator area, heater power, mass, time, money, schedule, etc)..... Many times the limits can be adjusted. It never hurts to ask!



DEVELOPING THE REQUIREMENTS TABLE

“Test Qualification Goals”

16

THE PRIMARY DEVELOPMENT OF THE REQUIREMENTS TABLE IS FROM SYSTEMS REQUIREMENTS REVIEW (SRR) THROUGH PRELIMINARY DESIGN REVIEW (PDR). SOME UPDATES MAY BE MADE AFTER PDR BASED ON DESIGN MATURITY.

Test Margin Definitions

17

After the Op, Non-Op, and Turn-on Limits have been defined at SRR the thermal PDL can determine the qualification requirements for each component based on GEVS. The qualification margins depend on how the component is thermally controlled AND if the required margin testing.

Thermal Control Method

Passive Systems → Temperature controlled by coatings, radiators, MLI, doublers (no mechanical/electrical parts or working fluids) → increased temperature range cold/hot qualification

Active Systems → Non-passive temperature control (e.g. heaters, fluid loops, TECs, Louvers) → reduction in cold qualification margin if heater power margin is met

Fixed Set-Point → Active Control but at one temperature → no increase in temperature range; component is stressed through external environment variation

Thermal Margin Requirement

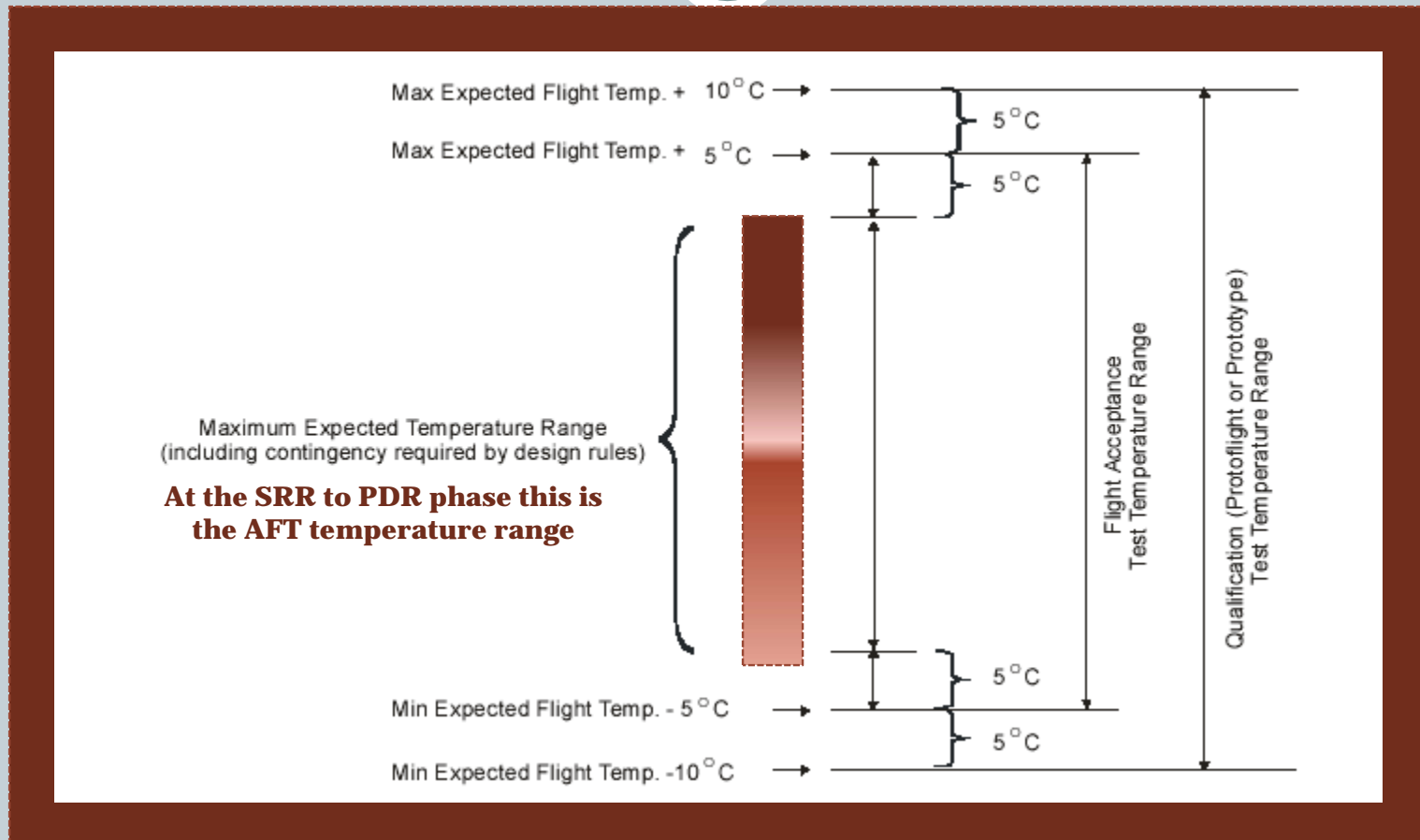
Qualification Thermal Margin – Environment used to prove the design of the test hardware by exposing design defects, to demonstrate robustness, to show tolerance to degradation (fatigue or wear) and to prove test condition tolerances. At GSFC Qual & Proto-qual (proto-flight) have the same requirements. Most hardware at GSFC is tested at this level.

Acceptance Thermal Margin – Margin of safety applied to worst-case analytic temperature predictions to account for uncertainties. Acceptance level is less stringent than Qualification Level and may be done on previously qualified designs.

Note: The definition of limits and the levels are different across NASA centers, private industry and other agencies.

Qualification (Protoflight/Prototype) & Flight Acceptance Thermal-Vacuum Temperatures from GEVS GSFC-STD-7000

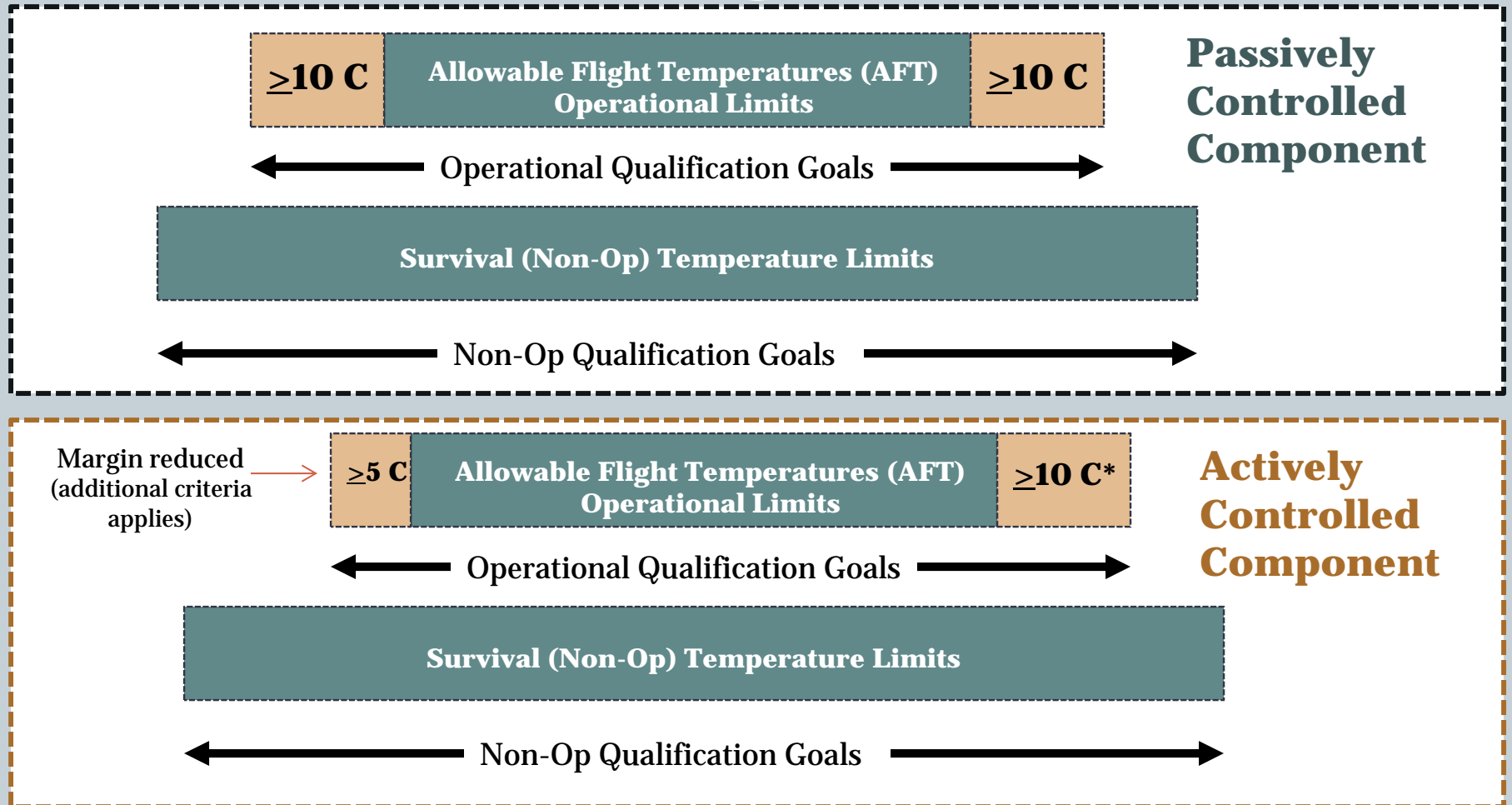
18



Note: this chart shows margins for a passively controlled component

Flight Allowable Qualification Goals Passively Versus Actively Controlled Component

19



* Maybe reduced to 5 C in special circumstances with branch review of design/analysis

From GEVS GSFC-STD-7000

20

For passively controlled systems, a **qualification** temperature margin of no less than 10°C above the “flight” maximum operating temperature and 10°C below the “flight minimum operating temperature” shall be used in establishing test temperatures.

The margins for **acceptance** previously qualified hardware may be reduced to 5°C, as long as testing to these levels does not preclude protoflight test levels from being achieved at higher levels of assembly.

The test margins for **actively** controlled hardware shall apply to both qual/protoflight and to acceptance testing:

- For actively controlled systems such as Heaters, ThermoElectric Coolers (TECs), Loop Heat Pipes (LHPs), Capillary Pumped Loops (CPLs), or other devices with selectable/variable set points, a test temperature margin of no less than 5°C shall be imposed on the respective set point band that is under control.
- For components/subsystems/payloads with operational heater circuits with fixed temperature setpoints, the margin may be reduced from 10°C to 5°C.
- If a component/subsystem/payload has an active control whose range is **not selectable/ variable** such that the control system will not allow the hardware to be stressed via temperature, then the stressing shall be induced by the increase or decrease of a heat load (internal or external) of at least 30 %. The active temperature control hardware shall maintain control under these stressed conditions.

The survival/safehold thermal-vacuum test shall consist of driving the element, without any test margin, to the desired temperature, and then returning that element to the qualification temperature to functionally check the operation. No component shall be allowed to exceed the non-operating temperature limit **with allowable tolerances**.

Example 2: Defining the Qualification Goals for the Requirements Table

21

The MEB PDL from example 1 said there was no problem having the survival limit at -35° C and that the box could be on between -35° C and +45° C but it may not be in spec. You adjusted your limits accordingly based on his updated information (see below). What would be the qualification goals?

Limit Type	Limits Table	Qualification Goals	Notes
Operational (AFT)	-20 to +30° C	-30 to +40° C	± 10° C GEVS
Survival	-35 to +55° C	-35 to +55° C	No Margin Required GEVS
Turn-On	-35 to +45° C	-35 to +45° C	No Margin Required

The table above assumes that the MEB is passively controlled. If an operational heater is used to maintain the MEB temperature then the qualification goal range could be reduced to -25 to +40° C. However since the MEB PDL has given the project a range of operation (in spec) of -30 to +40° C it would be better to adjust the AFT limit (see table below). It is always better to define a wider requirements range, especially at the SRR to PDR level since the design is evolving.

Recommended Change in Requirement if MEB was Actively Controlled by a Heater

Limit Type	Limits	Qualification Goals	Notes
Operational (AFT)	-25 to +30 C	-30 to +40 C	-5 /+ 10 C GEVS

Qualification Goals from Predictions

22

Qualification goals for Component level testing should never be based on predicts*. We strive to achieve these same “component level” goals for Subassembly, Instrument, and Observatory level testing. Identify components that will not meet qualification goals at higher levels of testing and compare to analytical predictions. The minimum qualification required margin is ± 15 C of worst-case predicts (± 10 C GEVS requirement and the ± 5 C modeling GOLD rules margin). Make sure that the project systems team and PDL understand the limitations. You may be required to perform additional cycles at the component level, change limits, or obtain a waiver.

Qualification goals may be based on predicts if the thermal model has been correlated. The minimum required qualification margin is ± 15 C of worst-case predicts.

*If a component’s design has been previously qualified to a very large temperature range the project may want to base the qualification goals on analysis. Testing to extreme levels would increase test schedule/cost and may not be possible because of adjacent hardware limitations. The branch recommends that the minimum qualification margin be widen to minimum of ± 20 C (op) and ± 10 C (non-op) since predicts would be with an uncorrelated model. Components may need wider margins in certain circumstances (e.g. Passively controlled isolated components, extreme environments, less mature designs, etc.)

GEVS Wording for When You Can Use Predictions to Set Qualification Goals

23

The max/min temperatures to be imposed during the TVAC test shall represent, as indicated above, a temperature range large enough, including margins, to induce stress during temperature cycling. The basis for the test temperatures shall be established either by program requirements or by predicted temperatures derived analytically using **a test verified model**. The latter means that worst case flight predictions will be generated from a thermal analytical model which has been **correlated satisfactorily to thermal balance test results**. When a thermal balance test precedes the thermal vacuum test, results from that test shall be used to refine the thermal vacuum test criteria, presuming that there is sufficient time to correlate the model and generate updated predictions prior to the thermal vacuum test. If predictions from a verified model are not available at the time of the thermal vacuum test, the basis shall be Project Office established, on-orbit maximum and minimum allowable operating limits. This basis shall constitute the “flight” temperature range to which test margins shall be applied.

Example 3: Qualification Goal from Analysis Predictions

24

A passively controlled potentiometer is on your instrument. This is used for a single-use deployment of a sun shield. It is a commercially available component whose design has been qualified to -65 to +125° C for other missions. These levels can not be achieved at the instrument level due to constraints on adjacent hardware. The predicted temperature range at deployment is -27 to 10° C. The predicted temperature range prior to deployment is -42 to +15° C and post-deployment is -55 to + 70° C. What should the potentiometer be qualified to?

The potentiometer should be cycled to a minimum op range of -47 to +30° C ($\pm 20^\circ$ C predicts*). AFT at deployment would be -37 to +20° C. The survival qualification range is dependant on the project requirement. In many instances the flight deployment hardware is not cycled to post-deployment values (e.g. NEI – non-explosive initiator). The minimum range for non-op qualification would be -52 to +30° C . Note that the non-op range should be at least $\pm 10^\circ$ C predicts. In the non-op “hot case” this would be +25°C. However the non-op qualification range should be at least as extreme as the op qualification range; therefore the non-op hot range must be at least +30° C.

Notes:

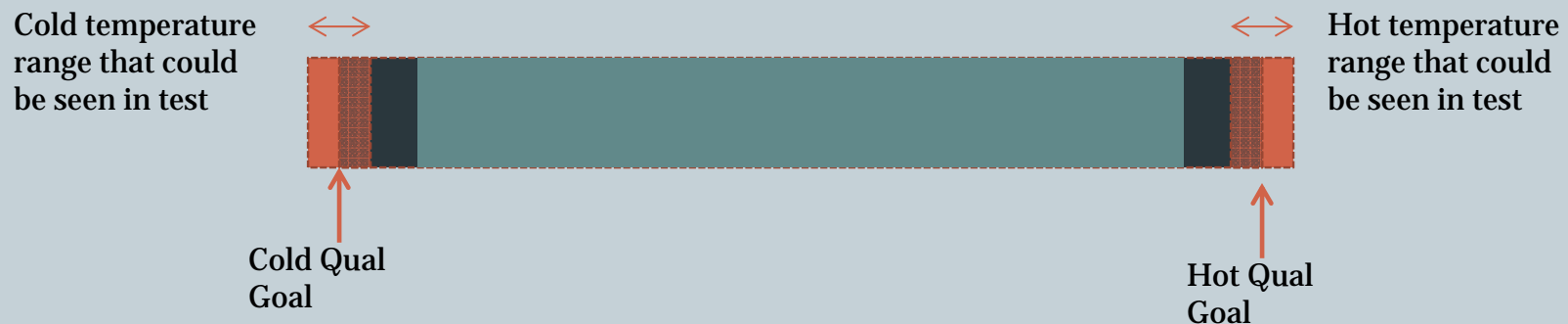
- For items that are deployed multiple times in a mission the post-deployment predictions should be used to set survival qualification limits.
- If the thermal model has been correlated then then the cycling range can be reduced to $\pm 10^\circ$ C predicts operationally and $\pm 0^\circ$ C predicts survival. Always adjust predicts based on correlation delta in a conservative manner.
- The test red survival limit can be set at -65 to +125° C since the component has been qualified to these levels for previous missions.

**branch recommendation per “Qualification Goals from Predictions” slide is at least $\pm 20^\circ$ C predicts unless model is correlated*

Qualification Goals and Limit Tolerances

25

- Allowable limits tolerances are added to the qualification goals (GEVS)
- GSFC Facilities and the thermal test conductors are required to take action to ensure that red limits are not hit. The Facility operators require at least 3° C of margin beyond the qualification goal.
- Hardware is taken to qualification goals during the test but temperature may be slightly outside of range for a limited period of time.
- The thermal PDL may determine that the a larger than 3 C tolerance is required on select components (i.e. light weight, extreme environment, or isolated).
- The Component PDL and project systems engineer should be in agreement that the hardware may be taken to the qualification goal plus tolerance. Otherwise the qualification goal and table must be updated. Include a note with the requirements table that a test tolerance will be added to qualification goals to determine sensor limits in test.



DEVELOPING THE TEST SENSOR LIMITS SPREADSHEET

26

**THIS ACTIVITY IS DONE PRIMARILY AFTER
THE PRELIMINARY DESIGN REVIEW (PDR).
A SPREADSHEET IS CREATED FOR EACH TEST
DUE TO VARIATIONS IN SENSOR LOCATION
AND TEST CONDITIONS**

Spreadsheet of Sensor Limits

27

- After PDR the table of limits and qualification goals should be complete. There may be updates based on design maturity that is vetted through the systems engineering team. The branch recommends that the project has the table under configuration management after PDR.
- The next product that the thermal PDL must develop is the test limits for each sensor (both flight and test sensors). The Thermal PDL must:
 - Base the spreadsheet on the requirements table and pretest analysis.
 - Understand where and when the requirement tables limits apply.
 - Know the gradients within components. This may vary with test configuration and/or hardware state. Actual sensor limits at “non-requirement” locations are adjusted based on gradients.
 - Apply appropriate test tolerances to limits.
 - Define both Red and Yellow Limits
 - Get Component PDLs to review and approve spreadsheet prior to test

Yellow Versus Red Test Limits

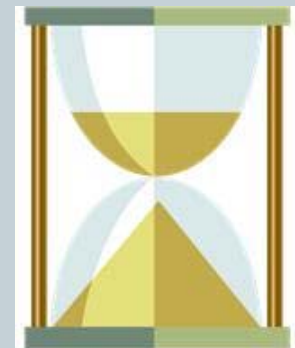
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Red limits represent a level that the hardware should not exceed. Damage may result if red limits are exceeded.



Yellow limits represent a condition where the hardware will not be harmed. Yellow limits should be set so that they alert test conductors to issues and allow them sufficient time to react before a red limit is hit.



Example 4: Determining the Test Sensor Limit in the Database at the Requirement Location

29

From example 2 the passively controlled MEB has the following limits and qualification goals established at the interface location.

Limit Type	Limits Table	Qualification Goals	Notes
Operational (AFT)	-20 to +30° C	-30 to +40° C	$\pm 10^{\circ}$ C GEVS
Survival	-35 to +55° C	-35 to +55° C	No Margin Required GEVS
Turn-On	-35 to +45° C	-35 to +45° C	No Margin Required

The thermal PDL has received concurrence from the component PDL/systems that a limits tolerance of $\pm 3^{\circ}$ C can be used in developing the sensor limits in the database for op and non-op limits. However the hot turn has a NTE temperature of +45° C. What are the red and yellow limits at the interface that should be set?

Limit Type	Qualification Goals	Limits Tolerances	Test Red Limits Sensor at Interface	Widest Test Yellow Limits I/F sensor
Operational	-30 to +40° C	$\pm 3^{\circ}$ C	-33 to +43° C	-31 to +41° C
Survival	-35 to +55° C	$\pm 3^{\circ}$ C	-38 to +58° C	-36 to +56° C
Turn-On	-35 to +45° C	-3/+0° C	-38 to +45° C	See note below

Yellow maximum range $\pm 1^{\circ}$ C outside of goal

- The turn-on limits are typically enforced by writing a conditional step in the test procedure instead of changing the limits database.
- The yellow limits listed above represent the widest limits allowable. The thermal PDL's engineering judgment must be used to establish the yellow limits to adequately warn personnel so that the red limit is not exceeded.

Sensor Position

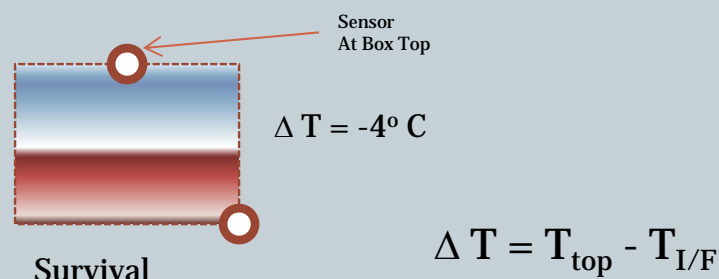
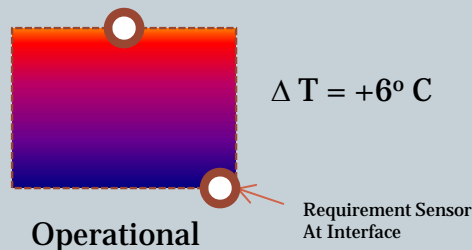
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- The test sensor limits that are put into flight and test data collection systems (TVDS) must take into account the location of sensors with respect to the requirement. The test sensor limits may be outside the “requirement levels” due to the gradients within the component.
- Branch recommends that the red sensor limits encompass the entire box temperature range (slightly wider range of limits) since gradient predictions are based on an uncorrelated model. (see example)
- The component PDL **MUST** approve the test sensor limits.

Example 5 : Test Limits and Sensor Position

31

The MEB requirement was based on the interface temperature. Sensor limits for the interface sensor were set per example 4. There is a 6° C linear gradient from top-to-bottom of the box operationally. When the box is off the gradient reverses to a -4° C gradient. What would be the test temperature limits of the sensors at the interface, and the top of the box?



Limit Type	Qualification Goals	Limits Tolerances	Limit Type	Test Limits Sensor @ I/F Example 4	Test Limits Sensor @ Top Adding Gradient Predictions*	Test Limits Sensor @ Top Branch Recommended Range*
Operational	-30 to +40° C	±3° C	Yellow**	-31 to +41° C	-25 to +47° C	-31 to +47° C
			Red	-33 to +43° C	-27 to +49° C	-33 to +49° C
Survival	-35 to +55° C	±3° C	Yellow**	-36 to +56° C	-40 to +52° C	-40 to +56° C
			Red	-38 to +58° C	-42 to +54° C	-42 to +58° C

*The component PDL must verify all sensor test limits. Branch recommends widest limits that PDL verifies that the hardware is safe since gradient predictions are based on uncorrelated models.

** Yellow is at discretion of thermal PDL values in table are the maximum extremes of the range recommended

Branch Interpretation of GEVS

32

GEVS:

Temperatures shall not exceed allowable qualification temperatures for extended periods of time. This may constrain the test to be driven by those components with the smallest allowable temperature range. Also, for testing at higher levels of assembly, the “red limits” (not-to-exceed temperatures) shall be established based on temperatures actually achieved during testing at lower levels of assembly.

The Quandary is that if a red limit must be based on the lower levels of assembly by definition at higher levels of assembly the component must be qualified 2 or 3° C LESS than at the component level.

Branch Guidelines in Implementation

- Keep sensor limits consistent between tests
- Adjust qualification soak goal tolerances accordingly

See example on next page on implementation

The soak goal tolerance describes the range of temperatures that would be acceptable for actual qualification (not the limit tolerance).

The thermal PDL defines this in the test plan (± 2 C is assumed for the example)

Example6: Progression of Qualification Goals and Associated Tolerances

33

The actual component qualification temperatures for example 5 are listed below. What are the qualification goals/tolerances that would be applied for higher levels of testing?

Cold Goal set to the value that was achieved in the component level test

Hot Goal set to the qualification goal

Limit Type	Qualification Goals Component Level	Red Test Limit of Sensor	Actual Qualification Component Level	Qualification Goals Higher Level	Actual Qualification Higher Level
Op (soak goal tolerance)	-30 to +40° C (±2° C) (± 2° C)	-33 to +43° C (includes ±3 C limits tolerance)	-29 to +41° C	-29 to +40° C (-0/+2° C) (-2/+1° C)	-28 to +39° C
Non-Op (tolerance)	-35 to +55° C (±2° C) (± 2° C)	-38 to +58° C (includes ±3 C limits tolerance)	-35 to +52° C	-35 to +52° C (-0/+2° C) (-2/+0° C)	-33 to +50° C

Note that the goal tolerances for the higher level qualification specified in the test plan are set to achieve the temperature levels seen in the component level test without exceeding them for a substantial period of time. The Red Limits for the sensor can remain -33 to +43° C (op) and -38 to +58° C (non-op) throughout the test program. It is recommended that yellow limits be adjusted at the higher level qualification test to alert operators that temperatures are near qualification goals .

Hot Goal set to the value that was achieved in component test non-op

Developing the Sensor Test Limits Spreadsheet

Reality of Testing

34

- Understand how the limits are changed (op versus non-op) in the test system. Systems may require that limits be **MANUALLY** changed (line-by-line) by the operator during testing. Human error can occur.
- Identify Non-op and Op limits changes and when they apply during test. (Note that some components may be OFF when the spacecraft or instrument is operational). Understand when and how to change flight sensor limits during the test.
- Each terminal may need to be updated when you change limits of flight sensors -> Make sure everyone is using consistent and correct limits.
- General branch policy: Do not plan to take hardware to temperatures more extreme than in previous testing UNLESS the project management, quality assurance, and the branch have approved. This is implemented through the qualification goals listed in the test plan. Throughout the test program (1) The red limits can remain consistent and (2) the yellow limits can be adjusted to reflect the updated qualification goals.

Defining and Applying Limits for Test and Flight

35

LIFECYCLE PHASE

DEFINING SENSOR LIMITS FOR FLIGHT

Yellow Versus Red Flight Limits

36



Red limits represent a level that the hardware should not exceed. Damage may result if red limits are exceeded.

- The branch policy is that the red limits are based on the extremes that the hardware has seen during the qualification program.



Yellow limits represent a condition where the hardware will not be harmed.

- The branch requires that yellow limits are set so that they alert operators to issues (such as non-nominal conditions) and that there is sufficient time to react before a red limit is hit.
- Yellow Op limits should be at or within the extremes that would not compromise science data. They must be at or within the flight allowable temperatures.
- The PDL should use engineering judgment to set the yellow limits. Typically there is at least 5° C between red and yellow limits. However lightweight/isolated components or components subjected to extreme environments may require a larger delta.
- A method utilized by some branch members is to set the yellow flight limits at the extremes predicted by the correlated thermal model. If this method is used look at model correlation and adjust limits if necessary.
- Yellow limits may be modified after launch based on flight temperatures.

Developing the Sensor-by-Sensor Flight Limits Spreadsheet

37

- Utilize requirements table with worst-case sensor test gradients
- Flight Software may have a default limit set of limits with “overlays” that can be commanded depending on the state of the payload.
- Limits can be overridden at individual terminals → know what limits are active.
- Define Limits Set → Keep it as simple as possible

Which components are operating during this phase of the mission or hardware state?

- Example: A satellite original limits for safehold had the reaction wheels with “non-op” values. However since these are critical to maintaining S/C orientation they were operating. The misunderstanding in when limits applied led to having to replace survival heater thermostats to maintain the wheels at op levels.

Example 7: Implementing Flight Limits

38

Given the actual temperatures that the sensor achieved in example 6 what would be the flight red/yellow limits?

Limit Type	Limits Table Requirement	Red Test Limit of Sensor	Actual Qualification Component Level	Actual Qualification Higher Level	Flight Red Limit	Possible Flight Yellow Limits
Op	-20 to +30° C (AFT)	-33 to +43° C	-29 to +41° C	-28 to +39° C	-29 to +41° C	-21 to +31° C
Non-Op	-35 to +55° C	-38 to +58° C	-35 to +52° C	-33 to +50° C	-35 to +52° C	-30 to +47° C

- The branch policy is that the flight red limit shall be no wider than the maximum level of temperatures seen during the qualification program.
- The thermal PDL may utilize more narrow limits based on their engineering judgment. For example they may elect to use values seen in the higher level qualification if the interface/gradients seen in component level testing was not flight-like.
- Yellow limits are set by the thermal PDL to ensure that the operators are alerted to non-nominal conditions and allow sufficient time to react prior to exceeding red limits. The branch recommends a minimum of 5° C difference between yellow and red limits. It is also recommended that the op yellow limits be set no more than 1° C outside of AFT. Engineering judgment in setting the yellow limits is particularly important for cryogenic systems, high temperature systems, light-weight components, and components exposed to extreme environments.

Defining and Applying Limits for Test and Flight

39

SUMMARY

Summary - General

40

- The method for setting limits shown in this presentation is the Goddard Thermal Branch standard policy. Other NASA centers and private industry may utilize different standards and definitions of limits.
- Limits continually evolve throughout the project lifecycle.
- Thermal limits should be based on hardware limitations
- Understand how limits are applied for mission modes (e.g. op/non-op).
- Know the control method (active, passive, fixed set-point) and margins requirements.
- Develop Requirements Table of Limits and Qualification Goals, and Sensor Spreadsheets of Test/Flight Limits.